1-1-2009

Martellia and associated Middle Ordovician brachiopods from the Katkoyeh Formation, east-central Iran

Ian G. Percival
Geological Survey of New South Wales, ian.percival@industry.nsw.gov.au

Anthony J. Wright
University of Wollongong, awright@uow.edu.au

Robert S. Nicoll
Australian National University

Mir Alireza Hamedi
Tehran, Iran

Martellia and associated Middle Ordovician brachiopods from the Katkoyeh Formation, east-central Iran

Abstract

The palaeontology and stratigraphy of the Ordovician if Iran has been the subject of considerable research over the past 15 years, revealing biogeographically significant faunas whose affinities are shared both with peri-Gondwanian terranes and continental blocks. Documentation of the composition and ages of these faunas, many of which are still poorly known, is critical to constraining palaeogeographic reconstructions of the time.

Keywords

Brachiopods, conodonts, Middle Ordovician, Katkoyeh Formation, Iran, GeoQUEST

Publication Details

Percival, I. G., Wright, A. J., Nicoll, R. S. & Hamedi, M. Alireza. (2009). Martellia and associated Middle Ordovician brachiopods from the Katkoyeh Formation, east-central Iran. Memoirs of the Association of Australasian Palaeontologists, 37 315-325.

Martellia and associated Middle Ordovician brachiopods from the Katkoyeh Formation, east-central Iran

IAN G. PERCIVAL, ANTHONY J. WRIGHT, ROBERT S. NICOLL & MIR ALIREZA HAMEDI

PERCIVAL, I.G., WRIGHT, A.J., NICOLL, R.S. & HAMEDI, M.A., 2009:12:24. *Martellia* and associated Middle Ordovician brachiopods from the Katkoyeh Formation, east-central Iran. *Memoirs of the Association of Australasian Palaeontologists 37*, 315-325. ISSN 0810-8889.

Three species of brachiopods, including *Martellia shabdjerehensis* sp. nov. *Leptellina*? sp., and *Paralenorthis* sp. are described from the Katkoyeh Formation at Shabdjereh, northwest of Kerman in east-central Iran. The brachiopods suggest biogeographic affinities with South America, South China and (less so) Kazakhstan. The accompanying conodont fauna indicates a probable Middle Ordovician age (*Lenodus variabilis* Zone, early Darriwilian) that accords with the age interpreted from co-occurrence of *Martellia* and *Paralenorthis*. This new information clarifies the age of this isolated exposure of the Katkoyeh Formation, implying it correlates with the middle part of the formation in its type section to the east.

I.G. Percival (ian.percival@industry.nsw.gov.au), Geological Survey of New South Wales, Industry & Investment NSW, W.B. Clarke Geoscience Centre, 947-953 Londonderry Road, Londonderry NSW 2753, Australia; A.J. Wright (tony.wright@optusnet.com.au), School of Earth and Environmental Sciences, University of Wollongong, Wollongong NSW 2522, Australia; R.S. Nicoll (bnicoll@velocitynet.com.au), Department of Earth and Marine Science, Australian National University, Canberra ACT 0200, Australia; M.A. Hamedi (mir_alireza_hamedi@yahoo.com), Tehran, Iran. *Received 21 August 2009.*

Keywords: Brachiopods, conodonts, Middle Ordovician, Katkoyeh Formation, Iran.

THE PALAEONTOLOGY and stratigraphy of the Ordovician of Iran has been the subject of considerable research over the past 15 years, revealing biogeographically significant faunas whose affinities are shared both with peri-Gondwanan terranes and continental blocks, and the collage of terranes comprising Kazakhstan. Documentation of the composition and ages of these faunas, many of which are still poorly known, is critical to constraining palaeogeographic reconstructions of the time.

Hamedi (1995) recognised a thin (34 m) sequence of Ordovician strata of limited outcrop extent near Shabdjereh, northwest of the city of Kerman in east-central Iran, and west of the Kuhbanan Fault (Fig. 1); approximate coordinates for this locality are: 31°5′N, 56°10′E. The sequence in the section which yielded the fauna analysed here was described by Hamedi (1995, p. 44) as follows: "The basal part of the sequence contains a thin, poorly sorted, matrix-supported conglomerate, overlying the Hatkan Dolomite disconformably. The overlying part of the sequence consists of 16.3 m of dark grey and red trilobite-bearing limestone, pale green shale and gypsiferous shale, representing a shallow marine transgression. The upper part consists of 8.5 m of fine red sandstone, shale and conglomeratic sandstone representing a regressive facies." Hamedi assigned this sequence to the Katkoyeh Formation of Rickards *et al.* (1994, 2001) which was based on exposures in the Gezueh gorge section above Katkoyeh village, north of Kerman and east of Zarand (Fig. 1).

At Hamedi's locality AH 9-5 near the town of Shabdjereh, the Katkoyeh Formation is overlain unconformably by, or is faulted against, Silurian strata assigned to the Shabdjereh Formation (Hamedi 1995, 1997). A low diversity trilobite fauna from locality AH 9-5, including *Neseuretus ghavideli* Bruton *et al.*, 2004, *Nileus* sp. cf. *N. exarmatus* Tjernvik, 1956 and ?*Sinoparapilekia*, was documented by Bruton *et al.* (2004), who listed conodonts (identified by R.S. Nicoll and determined by him as questionably Llanvirn: see below for discussion of the age of this conodont fauna) from this locality. Unfortunately, Bruton *et al.* (2004) erroneously attributed an Arenig age to the beds at AH 9-5. A slightly older conodont fauna was described from the Katkoyeh Formation limestone in the gorge section above Katkoyeh village by Zhen *et al.* (2001); note that *Bergstroemognathus hubeiensis* An, 1981, recorded by Zhen *et al.* (2001) in the lower

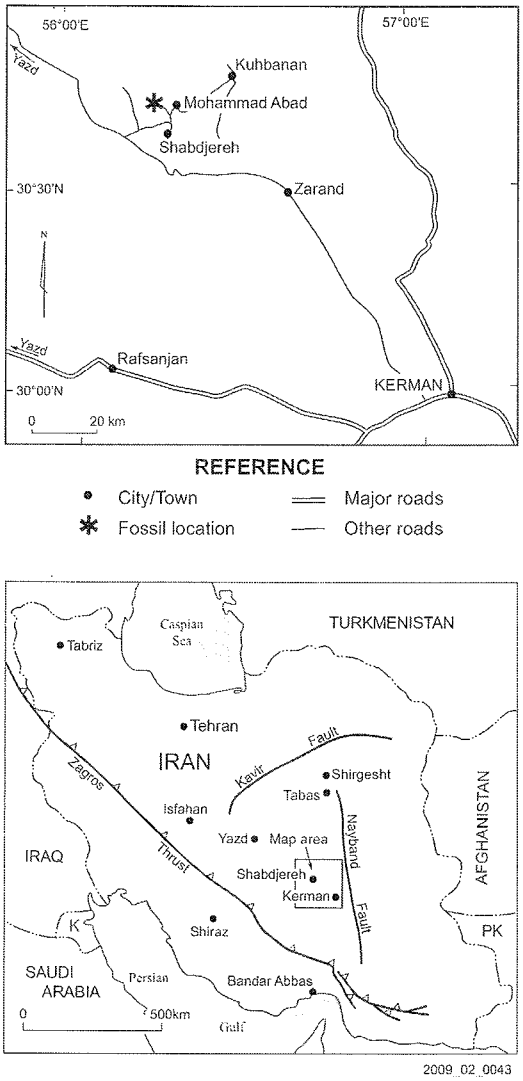


Fig. 1. Locality map, showing position of Shabdjereh region northwest of Kerman, and fossil sampling site. Detailed map adapted from Google Map image.

Katkoyeh Formation, was regarded by Zhen *et al.* (2006) as a junior subjective synonym of *B. extensus* (Graves & Ellison, 1941).

In this paper, three species of brachiopods – a new species of *Martellia*, *Leptellina*? sp. and *Paralenorthis* sp. – are described from the Shabdjereh locality. The brachiopods are mostly articulated, as are most trilobites at this locality, and were collected weathering out from the marl outcrops first by Hamedi and later by Wright. Other fauna present at this locality include a large unidentified strophomenoid? brachiopod (represented by one valve exterior, shown here in Fig. 2R), and rare indeterminate orthoceroid nautiloid fragments. The red colour of the host strata strongly suggests that the fossiliferous level at Shabdjereh can correlated with the middle unit of the Katkoyeh Formation at Banestan (Bassett *et al.* 1999, p. 484).

AGE OF THE KATKOYEH FORMATION

In its type area above Katkoyeh village (Rickards *et al.* 1994), the Katkoyeh Formation ranges in age from late Arenig to late Caradoc or possibly Ashgill (Dapingian to Katian of current usage) on present data.

A late Arenig age was suggested by Rickards *et al.* (1994), and reiterated by Hamedi *et al.* (1997), based on very limited graptolite data. A much more diverse graptolite fauna, described by Rickards *et al.* (2001) from a locality at the northern end of the Banestan valley, indicated a late Arenig (possibly early Llanvirn) age. In terms of international global Ordovician subdivisions, this probably equates to the early Darriwilian, or else is possibly late Dapingian.

Reitz & Davoudzadeh (1995) reported studies of acritarchs from the Banestan area, to which they ascribed a Middle Ordovician (Llandeilo to Caradoc, i.e. Darriwilian to Sandbian) age; their exact locality is unclear but probably was in the graptolitic unit at Banestan.

Bassett *et al.* (1999) recognised three faunal units in the Katkoyeh Formation. Their Unit A includes the late Arenig graptolitic unit at Banestan. Unit B, characterised by a bryozoan-*Rostricellula* fauna, also occurs at Banestan, and was considered by Bassett *et al.* (1999) to have a maximum age of Llandeilo, although this was discounted by Ebbestad *et al.* (2008, p. 606). Unit C occurs in the Gezueh gorge sequence; a Late Ordovician (Caradoc-Ashgill) age was suggested by Hamedi *et al.* (1997) on the basis of the occurrence of the conodont *Icriodella* sp. cf. *I. superba*; Bassett *et al.* (1999) used the presence of the brachiopod *Drabovia* aff. *crassior* to support a late Caradoc age but noted that the occurrence of *Cryptothyrella* may indicate an Ashgill age.

Ross *et al.* (2000) described Late Ordovician (Caradoc) bryozoans from two levels in this formation, mostly from the locality in the Gezueh Gorge to which Hamedi *et al.* (1997) ascribed a Caradoc-Ashgill age, based on conodonts identified by Nicoll. They also described bryozoans from Unit B at Banestan, but the unfounded suggestion (Ross *et al.* 2000, p. 333) that these beds are turbidites has not been substantiated and, in fact, has been indirectly refuted by Ebbestad *et al.* (2008) who interpreted gastropods from this locality as indicative of a shallow water environment, thus supporting Bassett *et al.* (2004) who identified the fauna as a

BA2-3 assemblage. Further details of the diverse fauna in the upper part of the formation, in the Banestan section and the Gezueh gorge section, have been provided by Bassett *et al.* (1999, 2004), Dastanpour *et al.* (2006) and Ebbestad *et al.* (2008).

Zhen *et al.* (2001) described conodonts from the limestone low in the type sequence of the Katkoyeh Formation in Desuyeh Gorge and concluded the fauna should be correlated with the *Serratognathus bilobatus* conodont Zone of North China (equivalent to the *Paroistodus proteus* conodont Zone of the late Tremadocian).

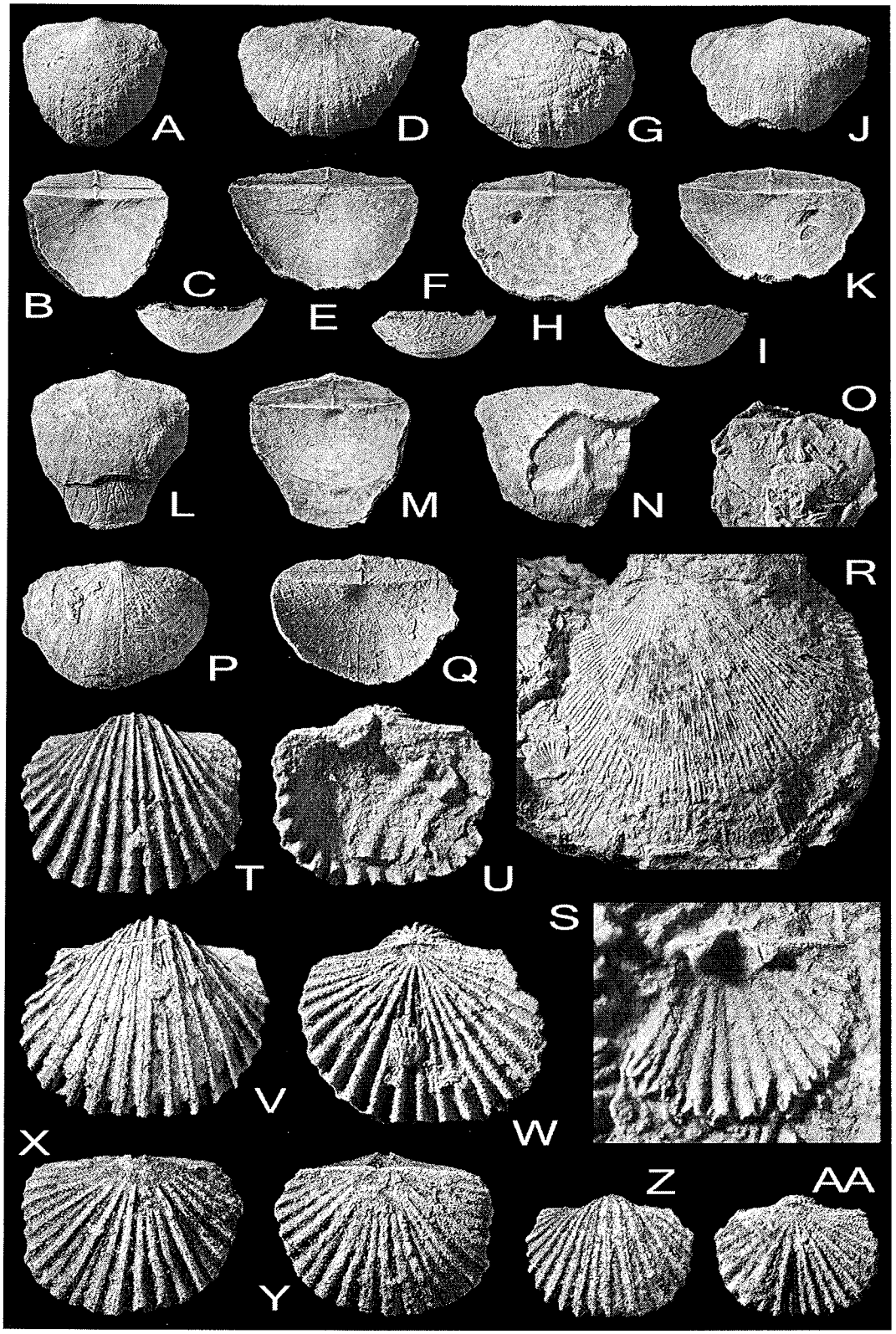
The suggestion by Turvey (2005, p. 575) and Ghobadi Pour *et al.* (2006, p. 558) that *Neseuretus ghavideli* is best synonymised with *Neseuretinus birmanicus* (Reed, 1906) was subsequently formalised by description of Iranian material of this species by Ghobadi Pour & Popov (2009). The late Darriwilian age proposed by Ghobadi Pour *et al.* (2006) for the occurrence of *N. ghavideli* in the upper part of the Shirgesht Formation at Dahaneh-e-Kolut is based on co-occurrence of the trilobite *Neseuretinus* and the brachiopod *Nicolella* in the Alborz Mountains but is not, as far as we are aware, supported by any published conodont data. This age assessment contrasts with the opinions of Hamedi *et al.* (1997), Bassett *et al.* (1999) and Bruton *et al.* (2004) who asserted that the faunas from the Shirgesht Formation range in age from Tremadoc to no younger than Arenig. If the Shabdjereh material assigned to *Neseuretus ghavideli* by Bruton *et al.* (2004) (none of which was illustrated) is conspecific with *Neseuretinus birmanicus*, and is early Darriwilian as suggested herein (based on conodont data), then the occurrences of *Neseuretinus* in the Shirgesht and Katkoyeh formations are essentially the same age.

The 95 conodont elements or fragments recovered from the Katkoyeh Formation at Hamedi's locality AH 9-5 have a conodont colour alteration index (CAI) of 4 to 5. Few of the elements are well enough preserved to be even tentatively identified to species level. The fauna consists of *Erraticodon* cf. *E. balticus* Dzik, 1978 (28 elements and fragments), *Scolopodus* aff. *S. princeps* Bagnoli & Stouge, 1997 (10 elements), *Drepanoistodus* sp. (36 elements), *Eoplacognathus*? sp. (27 elements and fragments) and *Prioniodus* sp. (3 elements). The ramiform fragments of the *Erraticodon* elements appear to have an enlarged denticle on the process, a feature of *E. balticus*. The *Scolopodus* elements have numerous costae on their lateral faces, but costae numbers of 10 to 14 are fewer than the counts of 16 to 18 suggested by Bagnoli & Stouge (1997) for *S. princeps*. The Pa elements that may be assignable to *Eoplacognathus* consist only of process fragments and no central element core is present to assist identification; associated ramiform elements are similar to those of the apparatus of *Eoplacognathus*.

An early Darriwilian age (*Lenodus variabilis* Zone) is interpreted for this limited fauna, based on the identification of the *Erraticodon* elements. Bagnoli & Stouge (1997) suggest a slightly older age for *Scolopodus princeps*, but our material is sufficiently distinct from that species to suggest that it may not be conspecific. Although there are uncertainties with this age dating, it accords with the general age determined from the brachiopod fauna.

AGE AND BIOGEOGRAPHIC AFFINITIES OF BRACHIOPODS

The dominant species at the Shabdjereh locality is *Martellia shabdjerehensis* sp. nov., which is the first record of this genus in Iran. Its occurrence is consistent with the age range of other species of *Martellia*, known from South China, the Chu-Ili terrane of Kazakhstan, and the Precordilleran Basin of Argentina, and its presence in Iran is certainly to be expected from this wider distribution in other peri-Gondwana terranes and nearby continental blocks. Elsewhere, *Martellia* is represented by *M. mesocosta* (Benedetto, 1987) and *M. talacastoensis* (Benedetto, 1987) in the San Juan Formation (early to mid Darriwilian) of Argentina (Benedetto 2003, p. 199); *M. reliqua* Popov, Vinn & Nikitina, 2001 and *M. fecunda* (Popov, Vinn & Nikitina, 2001), both from the Uzunbulak Formation (early Darriwilian) of the Chu-Ili range in south Kazakhstan (Popov *et al.* 2001; Nikitina *et al.* 2006); and several species from South China, occurring in the Dawan Formation and equivalent units of early Middle Ordovician age. These include the type species *M. giraldii* (Martelli, 1901) and *M. ichangensis* Wang, 1956 (and its synonyms *M. orbicularis* Zeng, 1977, *M. fenxiangensis* Zeng, 1977 and *M. transversa* Fang in Zeng, 1977). Xu & Liu (1984) assigned an early Middle Ordovician age (*Didymograptus nexus* and *Glyptograptus sinodentatus* graptolite zones) to these occurrences of *Martellia*. Based on additional research, Zhan *et al.* (2005, fig. 6) depicted the range of *Martellia* in South China as extending from the base of the *Didymograptus eobifidus* graptolite Zone (Early Ordovician, Floian) to the top of the *Undulograptus austrodentatus* graptolite Zone (Middle Ordovician, early Darriwilian). This range was further extended to the late Darriwilian by the occurrence of *Martellia* in the Shihtzupu Formation in Yunnan Province (Zhan & Jin 2005).


A
D
G
J
B
C
E
F
H
K
I
L
M
N
O
P
Q
R
T
U
S
V
W
X
Y
Z
AA

Paralenorthis is more widely distributed, occurring in South America (Bolivia and Argentina), North America (USA, Canada), China, Great Britain and France, according to Jaanusson & Bassett (1993). More recently, two species have been recorded from Peru (Gutiérrez-Marco & Villas 2007) and an unnamed species from Chile (González *et al.* 2007; Benedetto *et al.* 2008). Another new species has been described from northern Iran (Popov *et al.* 2009). It is interesting to note the temporal overlap of *Paralenorthis* and *Martellia*. Both genera are associated in the Dawan Formation (and correlative Meitan Formation) of Dapingian age in South China (Xu & Liu 1984), and they also co-occur at a slightly younger level (*Ahtiella argentina* zone, early-mid Darriwilian) in the San Juan Formation of the Argentine Precordillera (Benedetto 2003). Thus, although latest Early Ordovician (Floian) species of both genera are known in different localities, the probable age of the Shabdjereh fauna (based on co-occurrence of these brachiopods) is Middle Ordovician, ranging from Dapingian to mid Darriwilian. The likely early Darriwilian age determined from the associated conodont fauna confirms this age for the Katkoyeh Formation at the Shabdjereh locality.

TAXONOMY OF BRACHIOPODS (IGP)

Type and figured specimens (bearing the designation MMF) have been deposited in the Palaeontological Reference Collection of the Geological Survey of New South Wales, at Londonderry in western Sydney. Representative topotype material has been lodged with the Department of Geology, Golestan University, at Gorgan in Iran, with the Nanjing Institute of Geology and Palaeontology in China, and with the Geological Collections of the National Museum of Wales, Cardiff, United Kingdom.

For brevity, authorship of taxonomic hierarchy above genus level is not cited in the references; such sources are readily found in Williams *et al.* (2000). Authorship of the new species *Martellia shabdjerehensis* in the following section is attributable solely to Percival.

Phylum BRACHIOPODA Duméril, 1806
Subphylum RHYNCHONELLIFORMEA Williams, Carlson, Brunton, Holmer & Popov, 1996
Class STROPHOMENATA Williams, Carlson, Brunton, Holmer & Popov, 1996
Order STROPHOMENIDA Öpik, 1934
Superfamily PLECTAMBONITOIDEA Jones, 1928
Family LEPTELLINIDAE Ulrich & Cooper, 1936
Subfamily LEPTELLININAE Ulrich & Cooper, 1936

Leptellina Ulrich & Cooper, 1936

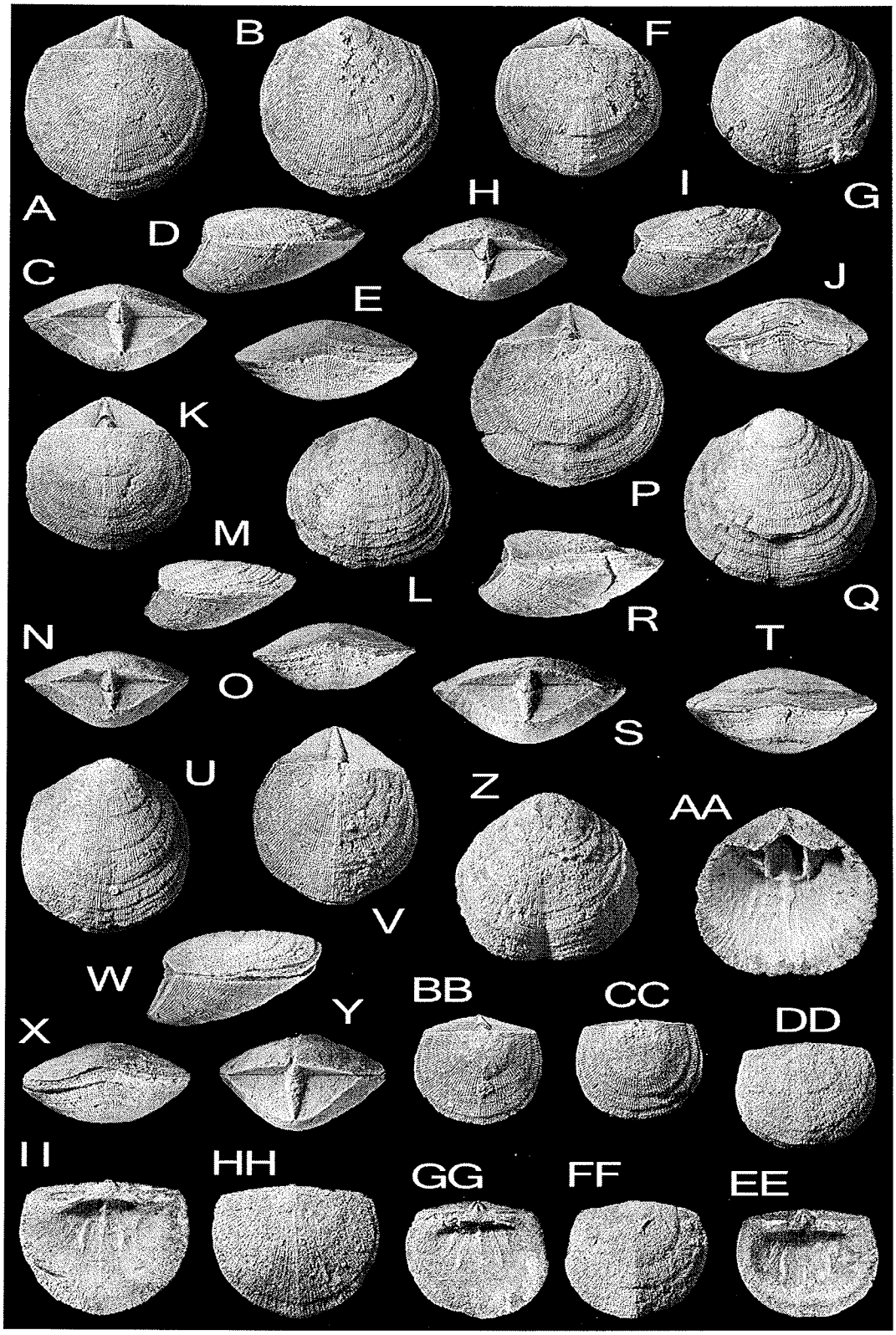
Type species. Leptellina tennesseensis Ulrich & Cooper, 1936.

Leptellina? sp. (Fig. 2A-Q)

Material. Figured specimens MMF 44973 – MMF 44980, MMF 44981 (unfigured), plus about 20 additional specimens.

Description. Shell concavoconvex, strongly compressed dorsoventrally with greatest shell curvature in anterior half; transversely semicircular to (less often) subquadrate in outline, widest at hingeline, about 15-17 mm in maximum width, length/width ratio of ventral valve averages 0.67 (mostly in range 0.61-0.73, rarely 0.89); maximum thickness of conjoined valves approximately 4-5 mm. Beak of ventral valve weakly pointed or rounded, posterior margin very obtusely divergent to acute lateral extremities. Ventral interarea apsacline, narrow but very wide; narrow, high pseudodeltidium covering almost all of delthyrium with remaining opening largely infilled by median ridge of cardinal process. Dorsal interarea slightly to considerably

Fig. 2. **A-Q**, *Leptellina*? sp., **A-C**, articulated shell in ventral, dorsal and lateral profile views, MMF 44973; **D-F**, articulated shell in ventral, dorsal and lateral profile views, MMF 44974; **G-I**, articulated shell in ventral, dorsal and lateral profile views, MMF 44975; **J-K**, articulated shell in ventral and dorsal views, MMF 44976; **L-M**, articulated shell (missing lateral extremities) in ventral and dorsal views, MMF 44977; **N**, ventral view of shell with ventral valve eroded to expose partial dorsal interior, MMF 44978; **O**, interior of dorsal valve (anteromedian portion obscured by adherent shell debris), showing cardinalia, MMF 44979; **P-Q**, articulated shell in ventral and dorsal views, MMF 44980. **R**, ventral valve exterior of indeterminate strophomenoid? brachiopod, MMF 44982; note dorsal valve interior of *Paralenorthis* sp. in lower left of this photograph (enlarged in S). **S-AA**, *Paralenorthis* sp., **S**, interior of juvenile ventral valve, MMF 44983; **T-U**, exterior and interior (obscured by adherent shell debris) of ventral valve, MMF 44984; **V-W**, articulated shell in ventral and dorsal views, MMF 44985; **X-Y**, articulated shell in ventral and dorsal views, MMF 44986; **Z-AA**, articulated shell in ventral and dorsal views, MMF 44987. Magnification: A-N, P, Q all x2, O x3; R X2; S x10, T-AA x5. All specimens from locality AH 9-5, Middle Ordovician section of Katkoyeh Formation, Shabdjereh area of east-central Iran.


B
F
A
H
I
G
D
C
J
E
K
P
M
L
Q
R
N
T
O
S
U
Z
AA
V
W
BB
CC
Y
DD
X
II
HH
GG
FF
EE

shorter, anacline to hypercline, with very narrow chilidium (or, possibly, paired chilidial plates). Ornament finely unequally parvicostellate, with 12-16 accentuated costellae radiating from beak of typical fully grown specimens, new costellae arising by intercalation along anterior margin of largest individuals; up to 2-3 accentuated costellae per mm, separated by up to 8 extremely fine microcostellae (only visible on better preserved specimens).

No natural ventral valve interiors were available, hence internal details unknown.

Dorsal valve interior poorly known (based on one almost entire juvenile and two partly obscured specimens); cardinal process trifid, bulbous, with prominent high median ridge and much lower flanking ridges, not undercut anteriorly (Fig. 2N); notothyrial platform lacking; socket ridges very short and delicate. Muscle field occupying about half valve length and width, bounded laterally by slightly raised ridges that are not undercut (Fig. 2N). A stout but low median septum extends to approximately two-thirds valve length where it merges with low raised platform rim that is not undercut; peripheral zone anterior to platform is marked by moderately deeply impressed mantle canals.

Remarks. Although numerous specimens of this form have been found, nearly all are articulated and tightly conjoined with interior features rarely visible. The strongly compressed shell thwarted attempts to mechanically separate the valves by grinding or calcining, and the valve composition differs little from that of the matrix so that selective dissolution by weak acid of the shell was unsuccessful. Hence, few internal details, necessary for definitive generic identification, are available. Details of the dorsal interior confirm attribution to the Leptellinidae, and further assignment to the Leptellininae is based on a perception (from a partly dissolved shell) of a relatively small ventral muscle field apparently confined to the posterior quarter of the valve.

The Iranian species conforms to the concept of *Leptellina* in all aspects, save for the extended height of the pseudodeltidium which covers almost all the delthyrium (in *Leptellina* the pseudodeltidium is typically restricted to the apex of the delthyrium which is largely open). In this one respect it more closely resembles *Acculina* Misius in Misius & Ushatinskaya, 1977, but that genus has a gently resupinate profile and an undercut platform in the dorsal valve. Until details of the ventral valve interior are revealed, it seems prudent to only tentatively assign the leptellinin from Shabdjereh to *Leptellina*. Its characteristic high pseudodeltidium recalls that of an unattributed species of *Leptellina* from the Middle Ordovician Shihtzupu Formation of Yunnan Province, South China (Zhan & Jin 2005, Fig. 11F).

Order BILLINGSELLIDA Schuchert, 1893
Superfamily POLYTOECHIOIDEA Öpik, 1934
Family TRITOECHIIDAE Ulrich & Cooper, 1936

Martellia Wirth, 1936

Type species. *Orthisina giraldii* Martelli, 1901; by original designation.

Diagnosis (emended from Popov *et al*. 2001). Tritoechid with a pseudospondylium; high notothyrial platform undercut anteriorly and supported by a median septum; anterior commissure variably uniplicate; ornament very finely multicostellate.

Martellia shabdjerehensis sp. nov. (Fig. 3 A-II)

Material. Holotype MMF 44988, paratypes MMF 44989 – 44997 (figured), MMF 44998 – 45002 (unfigured), plus more than 100 additional specimens.

Diagnosis. A species of *Martellia* with a broadly rounded anterior margin, and very weakly developed median ridges internally, particularly in the dorsal valve.

Etymology. Named for the local town of Shabdjereh.

Fig. 3. **A-II**, *Martellia shabdjerehensis* sp. nov., **A-E**, Holotype, articulated shell in dorsal, ventral, posterior, lateral and anterior views, MMF 44988; **F-J**, articulated shell in dorsal, ventral, posterior, lateral and anterior views, MMF 44989; **K-O**, articulated shell in dorsal, ventral, lateral, posterior and anterior views, MMF 44990; **P-T**, articulated shell in dorsal, ventral, lateral, posterior and anterior views, MMF 44991; **U-Y**, articulated shell in ventral, dorsal, lateral, anterior and posterior views. MMF 44992; **Z-AA**, exterior and interior views of ventral valve, MMF 44993; **BB-CC**, dorsal and ventral views of articulated shell, MMF 44994; **DD-EE**, exterior and interior views of dorsal valve, MMF 44995; **FF-GG**, exterior and interior views of dorsal valve, MMF 44996; **HH-II**, exterior and interior views of dorsal valve, MMF 44997. Magnification: all x2, except HH & II x3. All specimens from locality AH 9-5, Middle Ordovician section of Katkoyeh Formation, Shabdjereh area of east-central Iran.

Description. Shell about 15 mm in maximum length and width, maximum thickness of conjoined valves approximately 8 mm; profile biconvex to ventribiconvex; subpyramidal ventral valve is highest posteriorly and bears a shallow narrow median sulcus close to anterior margin in largest individuals (Fig. 3G, Q); dorsal valve often with weak narrow median fold (but not always developed); anterior margin generally broadly rounded but occasionally (in largest specimens) slightly obtusely angulate; commissure weakly uniplicate. Ventral valve outline variable from semicircular to transversely subquadrate to (rarely) elongately subovoid, with obtusely pointed beak; length to width ratio averages 0.93 (range 0.87-0.98). Dorsal valve outline more transversely semicircular to subquadrate with wide straight hingeline; average length to width ratio 0.83 (range 0.77-0.89); both valves with maximum width at about midlength, rarely equivalent to hinge width. Ornament very finely and evenly multicostellate, about four or five costellae per mm at anterior margin; concentric rugae or broadly spaced growth discontinuities prominent on some individuals (Fig. 3Q) but in others these are lacking or are nearly imperceptible. Ventral interarea relatively long (up to 0.25 valve length), generally apsacline but sometimes tending to nearly catacline; pseudodeltidium prominent but narrow, with minute open foramen at apex. Dorsal pseudointerarea anacline to almost hypercline, much shorter than that of opposing valve, with complete chilidium.

Ventral interior with robust pseudospondylium bounded laterally by stout vertical dental plates and enclosing pair of rectangular outer adductor scars, separated medially by thin low ridge bearing inner adductor tracks; pseudospondylium extends posteriorly beneath overhanging pseudointerarea, and occupies about 0.45 valve length and 0.25 valve width. Dental plates or lateral edges of pseudospondylium do not extend anterior to the muscle field. A low median ridge continues anteriorly from front edge of pseudospondylium to approximately half distance towards anterior margin. Mantle canals very faintly impressed.

Dorsal interior has single ridge-like cardinal process supported on massive notothyrial platform undercut anteriorly and extending transversely as gently divergent socket ridges; a very low median ridge (sometimes barely discernible) extends anteriorly from the underside of the notothyrial platform towards the middle of the valve where it disappears. Muscle field comprising weakly impressed divergent adductor scars bisected by two pairs of very low broad transmuscle ridges, the inner pair of which are longer and may extend into anterior third of valve. A low thickened subperipheral rim is infrequently developed (Fig. 3EE). Mantle canals not impressed.

Remarks. Popov *et al.* (2001), in their detailed review of genera comprising the Tritoechidae, noted the distinguishing characteristics of *Martellia* as possession of a pseudospondylium, a slightly uniplicate anterior commissure, very finely multicostellate ornament, high notothyrial platform overhanging anteriorly and supported by a median septum, and a subhexagonal shell outline with an acute anterior margin. In all aspects but the last mentioned, the new species of *Martellia* conforms to this concept of the genus. However, the variable outline of *M. shabdjerehensis* and the irregular development of a ventral sulcus (often lacking in all but gerontic shells) ensures that the sharply angular to somewhat produced anterior margin of other species never occurs in the new species. Illustrated here (Fig. 3) are examples of the range of shell outlines and profiles seen in a large collection of over 100 individuals from the one outcrop.

Zhan & Jin (2005) identified *M. ichangensis* Wang, 1956, as a senior synonym of *M. orbicularis* Zeng, 1977, on the basis that both shells are subcircular in outline with a weakly developed fold and sulcus. Popov *et al.* (2001) had earlier synonymised *Martellia fenxiangensis* Zeng, 1977, with *M. ichangensis*, and also *M. transversa* Fang in Zeng, 1977, with *M. orbicularis*, so that all four species, which occur together in the early Middle Ordovician Dawan Formation of South China, can now be considered the same taxon. They share with *M. shabdjerehensis* a broadly rounded anterior margin and a poorly defined to absent dorsal fold and ventral sulcus. Although *M. orbicularis* was previously excluded from the concept of *Martellia* by Popov *et al.* (2001) on this basis, this species is much closer to *Martellia* than to the only other broadly similar genus *Pomatotrema* Ulrich & Cooper in Schuchert & Cooper, 1932. Given the obvious plasticity of the tritoechid shell outline – a fact demonstrated by the inclusion by Popov *et al.* (2001, fig. 6.31-35) of what they termed an aberrant specimen (lacking a ventral sulcus and dorsal fold and hence with a broadly rounded anterior margin) in their new species *M. reliqua* – it would be better to encompass such variation within the concept of *Martellia*. Hence *M. ichangensis* (=*M. orbicularis*), as well as the new species *M. shabdjerehensis* are, together with all the other species recognised by Popov *et al.* (2001), included in a slightly expanded diagnosis of the genus which does not incorporate an acutely angular anterior margin as a defining characteristic. Such a diagnosis would also accommodate *Pomatotrema fecunda* Popov,

Vinn & Nikitina, 2001 which is here reassigned to *Martellia*, based on its prominent undercut notothyrial platform. This feature appears to be a consistent and diagnostic characteristic of the genus.

Species previously attributed to *Martellia* from South China and the Chu-Ili region of Kazakhstan are readily separated by their angulate anterior margins and reasonably pronounced uniplicate anterior commissure from *M. shabdjerehensis*, which also never develops as prominent a dorsal median septum as is present in all other species. Although the anterior commissure of the Argentine species, *M. mesocosta* and *M. talacastoensis*, tends to be nonplicate or slightly uniplicate, a low, narrow median fold is always present in these species, distinguishing them from *M. shabdjerehensis* in which this feature is much less marked or occasionally absent. As alluded to above, the new species is closest in outline and in weak development of fold and sulcus to *M. ichangensis*, but it clearly differs from that species (and its synonyms) in lacking a robust dorsal median septum (e.g. Zhan & Jin 2005, fig. 14C, D, F). Furthermore, the dental plates do not extend forward of the anterior margin of the pseudospondylium in *M. shabdjerehensis* and its ventral median ridge is much lower (contrasting with *M. orbicularis* of Zeng, 1977, pl. 15, figs 11 & 12 and *M. ichangensis* of Zhan & Jin 2005, fig. 14A, B), but otherwise the Chinese and Iranian species are generally similar in profile and outline. From atypical examples of *M. reliqua* Popov, Vinn & Nikitina, 2001 (such as that illustrated by Popov *et al.* 2001, fig. 6.31-35) *M. shabdjerehensis* can be distinguished by its more transverse outline in the majority of specimens.

Class RHYCHONELLATA Williams, Carlson, Brunton, Holmer & Popov, 1996
Order ORTHIDA Schuchert & Cooper, 1932
Suborder ORTHIDINA Schuchert & Cooper, 1932
Superfamily ORTHOIDEA Woodward, 1852
Family ORTHIDAE Woodward, 1852

Paralenorthis Havlíček & Branisa, 1980

Type species. Paralenorthis immitatrix Havlíček & Branisa, 1980.

Paralenorthis sp. (Fig. 2S-AA)

Material. Figured specimens MMF 44983 – MMF 44987.

Description. Shell relatively small, up to 8 mm in maximum dimension; outline transversely subquadrate, maximum width about midlength, length/width ratio: 0.77-0.83 (ventral valve), 0.72-0.75 (dorsal valve). Profile planoconvex with maximum curvature medially in ventral valve flanked by flattened posterolateral corners; dorsal valve with narrow median sulcus developing in anterior half; anterior commissure weakly uniplicate. Ventral valve beak slightly incurved; interarea low and narrow, extending to about half hinge-width, delthyrium open; dorsal interarea very low, barely visible. Ornament of strong angular costae that are separated by wider interspaces; only occasionally are new costae intercalated (e.g. Fig. 2X); 20-22 costae on fully grown individuals; concentric ornament or growth lines mostly lacking, although they are extremely weakly developed on some individuals (Fig. 2W, AA) as a fine granular pattern.

Ventral valve interior (Fig. 2 S, U) with robust teeth supported by dental plates that laterally bound small muscle field, on slightly thickened pad confined to posterior quarter of valve length. Remainder of interior is dominated by reflections of external costae.

Dorsal valve interior unknown.

Remarks. Detailed comparisons of this form, based on so few specimens and especially lacking interior details of the dorsal valve, with previously described species of *Paralenorthis* would be premature and unreliable, and so it is left under open nomenclature. The costae, which are sharply angular in cross section, might seem to be a distinguishing characteristic of the species from Shabdjereh, as the original diagnosis of the genus (Havlíček & Branisa 1980, p. 15) specifically mentions rounded ribs in the type species *P. immitatrix*. However, more recent description of *P. immitatrix* of uppermost Floian age from Peru demonstrates the presence of subangular costae (Gutiérrez-Marco & Villas 2007, fig. 5H). The much older *P. semnanensis*, described by Popov *et al.* (2009) from the lower Lashkarak Formation (late Tremadocian) of the eastern Alborz Mountains in northern Iran, is quite different in many aspects – it is considerably larger, with an evenly convex ventral valve profile, and completely lacks a sulcus in the dorsal valve. The ornament of *P. semnanensis* is also distinct from that of the Shabdjereh specimens in having a rounded rather than angular rib profile, except in initial growth stages.

ACKNOWLEDGEMENTS

We thank David Barnes (Industry & Investment NSW, Maitland) who photographed the brachiopods and prepared their illustrations. The locality diagram was drawn by Cheryl Hormann

with the assistance of Gary Colquhoun (both with Industry & Investment NSW, Maitland) who adapted an image from Google Map. We are grateful to Leonid Popov (Cardiff) and Juan Benedetto (Córdoba) for their helpful critiques of the manuscript. Ian Percival publishes with permission of the Director of the Geological Survey of New South Wales. Field work in Iran by Tony Wright was supported by the University of Wollongong, and facilities for research were made available by the School of Earth and Environmental Sciences, University of Wollongong. Ali Hamedi's field studies were funded by the Ministry of Mines and Metals, Iran. This paper is a contribution to IGCP Project 503: Ordovician Palaeogeography and Palaeoclimate.

REFERENCES

An T.X., Du G.Q., Gao Q.Q., Chen X.B. & Li W.T., 1981. Ordovician conodont biostratigraphy of the Huanghuachang area of Yichang, Hubei. 105-113 in Micropalaeontological Society of China (ed.), *Selected Papers of the First Academic Symposium of the Micropalaeontological Society of China (1979)*. Science Press, Beijing.

Bagnoli, G. & Stouge, S., 1997. Lower Ordovician (Billingenian – Kunda) conodont zonation and provinces based on sections from Horns Udde, north Öland, Sweden. *Bollettino della Società Paleontologica Italiana 35(2)*, 109-163.

Bassett, M.G., Dastanpour, M. & Popov, L.E., 1999. New data on Ordovician fauna and stratigraphy of the Kerman and Tabas regions, east-central Iran. *Acta Universitatis Carolinae, Geologica 43*, 483-486.

Bassett, M.G., Dastanpour, M. & Popov, L.E., 2004. Late Ordovician faunas of Kerman Province, east-central Iran. 15 in Hints, O. & Ainsaar, L. (eds), *WOGOGOB-2004 Conference Materials*. Tartu University Press, Tartu.

Benedetto, J.L., 1987. Braquiópodos clitambonitáceos de la formación San Juan (Ordovícico temprano), Precordillera de San Juan, Argentina. *Ameghiniana 24*, 95-108.

Benedetto, J.L., 2003. Brachiopods. 187-271 in Benedetto, J.L. (ed.), *Ordovician fossils of Argentina*. Secretaría de Ciencia y Tecnología, Universidad Nacional de Córdoba.

Benedetto, J.L., Niemeyer, H., González, J. & Brussa, E.D., 2008. Primer registro de braquiópodos y graptolitos ordovicicos en el Cordón de Lila (Puna de Atacama), norte de Chile. *Ameghiniana 45*, 3-12.

Bruton, D.L., Wright, A.J. & Hamedi, M.A., 2004. Ordovician trilobites of Iran. *Palaeontographica A 271*, 111-149.

Dastanpour, M., Evans, D.H. & Bassett, M.G., 2006. A new orthoceratid cephalopod from the Ordovician (Caradoc) of east-central Iran. *Geobios 39*, 337-345.

Dzik, J., 1978. Conodont biostratigraphy and paleogeographical relations of the Ordovician Mójcza Limestone (Holy Cross Mts, Poland). *Acta Palaeontologica Polonica 23*, 51-72.

Ebbestad, J.O.R., Bassett, M.G. & Popov, L.E., 2008. Ordovician (Caradoc) Gastropoda of the Katkoyeh Formation, Kerman Province, Iran. *Geobios 41*, 605-624.

Ghobadi Pour, M. & Popov, L.E., 2009. First report on the occurrence of *Neseuretinus* and *Ovalocephalus* trilobites in the Middle Ordovician of Iran. *Acta Palaeontologica Polonica 54*, 125-133.

Ghobadi Pour, M., Williams, M., Vannier, J., Meidla, T. & Popov, L.E., 2006. Ordovician ostracods from east central Iran. *Acta Palaeontologica Polonica 51*, 551-560.

Gonzalez, J., Niemeyer, H., Benedetto, J.L. & Brussa, E.D., 2007. The Ordovician Quebrada Grande Formation, Cordón de Lila (Antofagasta Region, northern Chile): stratigraphic and palaeogeographic significance. *Revista Geológica de Chile 34*, 277-290.

Graves, R.W. & Ellison, S., 1941. Ordovician conodonts of the Marathon Basin, Texas. *University of Missouri, School of Mines and Metallurgy, Bulletin 14*, 1-26.

Gutierrez-Marco, J.C. & Villas, E., 2007. Brachiopods from the uppermost Lower Ordovician of Peru and their palaeogeographical significance. *Acta Palaeontologica Polonica 52*, 547-562.

Hamedi, M.A., 1995. *Lower Palaeozoic sedimentology and stratigraphy of the Kerman region, East-Central Iran*. Unpublished Ph.D. thesis, University of Wollongong, 176 p.

Hamedi, M.A., 1997. Silurian transgression on fluvial sediments, and introducing the Shabdjereh Formation from east-central Iran. 84-94 in Amenie, S.H., Ramgbaname, M. & Kamami, A. (eds), *The First Annual Conference of the Geological Society of Iran, September 1995*. Tehran.

Hamedi, M.A., Wright, A.J., Aldridge, R.J., Boucot, A.J., Bruton, D.L., Chatterton, B.D.E., Jones, P., Nicoll, R.S., Rickards, R.B. & Ross, J.R.P., 1997. Cambrian to Silurian of East-Central Iran: new biostratigraphic and biogeographic data. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte 1997(7)*, 412-424.

Havlíček, V. & Branisa, L., 1980. Ordovician brachiopods of Bolivia (succession of assemblages, climate control, and affinity to Anglo-French and Bohemian provinces). *Rozpravy Československé akademie věd, řada matematických a přírodních věd 90*, 1-54.

Jaanusson, V. & Bassett, M.G., 1993. *Orthambonites* and related Ordovician brachiopod genera.

Palaeontology 36, 21-63.

MARTELLI, A., 1901. Fossili del Siluriano Inferiore dellos Schensi (China). *Bollettino della Società Geologica Italiana 20*, 295-310.

MISIUS, P.P. & USHATINSKAYA, G.T., 1977. Novye ordovikskie i siluriiskie strofomenidy Kazakhstana i Servenoi Kirgizii. 113-116 in Stukalina, G.G. (ed.), *Novye Vidy Drevnikh Rasteni i Bespozvonochnykh SSSR 4*. Nauka, Moskva.

NIKITINA, O.I., POPOV, L.E., NEUMAN, R.B., BASSETT, M.G. & HOLMER, L.E., 2006. Mid Ordovician (Darriwilian) brachiopods of South Kazakhstan. 145-222 in Bassett, M.G. & Deisler, V.K. (eds), *Studies in Palaeozoic Palaeontology*. National Museum of Wales Geological Series 25, Cardiff.

POPOV, L.E., GHOBADI POUR, M., BASSETT, M.G. & KEBRIA-EE, M., 2009. Billingsellide and orthide brachiopods: new insights into earliest Ordovician evolution and biogeography from northern Iran. *Palaeontology 52*, 35-52.

POPOV, L.E., VINN, O. & NIKITINA, O.I., 2001. Brachiopods of the redefined family Tritoechiidae from the Ordovician of Kazakhstan and South Urals. *Geobios 34*, 131-155.

REED, F.R.C., 1906. The Lower Palaeozoic fossils of the northern Shan states, Burma. *Memoirs of the Geological Survey of India, Palaeontologia Indica, New Series 2(3)*, 1-154.

REITZ, E. & DAVOUDZADEH, M., 1995. Ordovician acritarchs from the Banestan, Kerman area: paleobiogeographical evidence for a warm water environment. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte 1995(1)*, 488-500.

RICKARDS, R.B., HAMEDI, M.A. & WRIGHT, A.J., 1994. A new Arenig (Ordovician) graptolite fauna from the Kerman district, Iran. *Geological Magazine 133*, 35-42.

RICKARDS, R.B., HAMEDI, M.A. & WRIGHT, A.J., 2001. A new assemblage of graptolites, rhabdopleuran hemichordates and chitinous hydroids from the Banestan area, east-central Iran. *Alcheringa 25*, 169-190.

ROSS, J.R.P., HAMEDI, M.A. & WRIGHT, A.J., 2000. Late Ordovician (Caradoc) bryozoans from the Kerman district, east-central Iran. 329-335 in Cubilla, A.H. & Jackson, J.B.C. (eds), *Proceedings of the 11th International Bryozoology Association Conference*. Smithsonian Tropical Research Institute, Balboa.

SCHUCHERT, C. & COOPER, G.A., 1932. Brachiopod genera of the suborders Orthoidea and Pentameroidea. *Memoirs of the Peabody Museum of Natural History 4*, 1-270.

TJERNVIK, T.E., 1956. On the Early Ordovician of Sweden. *Bulletin of the Geological Institutes of the University of Uppsala 36*, 107-284.

TURVEY, S.T., 2005. Reedocalymenine trilobites from the Ordovician of central and eastern Asia, and a review of species assigned to *Neseuretus*. *Palaeontology 48*, 549-575.

ULRICH, E.O. & COOPER, G.A., 1936. New genera and species of Ozarkian and Canadian brachiopods. *Journal of Paleontology 10*, 616-631.

WANG, Y., 1956. New species of brachiopods [1]. *Scientia Sinica 5*, 157-176.

WILLIAMS, A., BRUNTON, C.H.C. & CARLSON, S.J. (eds), 2000. *Treatise on Invertebrate Paleontology, Part H. Brachiopoda (Revised), Vol. 3*. The Geological Society of America, Boulder, and The University of Kansas Press, Lawrence.

WIRTH, E., 1936. Über "*Clitambonites*" *giraldii* Martelli und *Yangtzeella poloi* Martelli aus dem Ordoviz Chinas. *Paläontologische Zeitschrift 18*, 292-302.

XU, H.K. & LIU, D.Y., 1984. Late Lower Ordovician brachiopods of Southwestern China. *Bulletin of Nanjing Institute of Geology and Palaeontology 8*, 147–235.

ZENG, Q.L., 1977. Brachiopoda. 27-69 in Hubei Institute of Geological Sciences (ed.), *Atlas of palaeontological illustrations from central and southern China. Part 1. Early Palaeozoic*. Geological Publishing House, Beijing.

ZHAN, R.B. & JIN, J., 2005. Brachiopods from the Middle Ordovician Shihtzupu Formation of Yunnan Province, China. *Acta Palaeontologica Polonica 50*, 365–393.

ZHAN, R.B., RONG, J.Y., CHENG, J.H. & CHEN, P.F., 2005. Early-Mid Ordovician brachiopod diversification in South China. *Science in China, Ser. D Earth Sciences 48*, 662-675.

ZHEN, Y.Y., NICOLL, R.S., PERCIVAL, I.G., HAMEDI, M.A. & STEWART, I., 2001. Ordovician Rhipidognathidae (Conodonta) from Australia and Iran. *Journal of Paleontology 75*, 186-207.

ZHEN, Y.Y., PERCIVAL, I.G. & LIU, J.B., 2006. Rhipidognathid conodonts from the Early Ordovician Honghuayuan Formation of Guizhou, South China. *Palaeoworld 15*, 194-210.